Intertemporal Emissions Trading and Allocation Rules: Gainers, Losers and the Spectre of Market Power

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Abstract

Stemming from politically given market imperfections in a tradable permits system, this paper develops a Stackelberg game with two types of non-cooperative agents to describe how a large -potentially dominant- agent may exercise market power at the expense of a competitive fringe.

In a dynamic framework with full forward and backward temporal flexibility (i.e. 1:1 Intertemporal Trading Ratio), this intra-industry model then suggests an optimal allocation criterion for grandfathered permits based on recent emissions.

This paper contributes to the permit trading literature by shedding some light on the decision to allow banking and borrowing, a debate which is typically overlooked by the debate to introduce the permits market itself among other environmental regulation tools. Provisional results are presented under perfect information.

***JEL* Classification:** L1, Q5 **Keywords:** emissions trading, banking, borrowing, market power, optimal control, differential game.

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Contents

1 Introduction

What happens on a tradable permits market when distortions occur as a consequence of the inital allocation? Whereas Hahn (1984) contributed first to this debate by demonstrating the non neutrality of permits allocation for an agent able to exert market power[1] in a static context and concerning the spatial exchange of permits only, this paper addresses the critical aspect of initial permits allocation in a dynamic context and concerning intertemporal emissions trading. Theoretical analyses remain scarce in this domain, even if the properties of banking (i.e. the ability to stock permits for future use) and borrowing (i.e. the ability to borrow permits from future periods) have been detailed. In a continuous time model under certainty, Rubin (1996) shows that an intertemporal equilibrium exists on a permits market from the viewpoint of the regulator and the firm, and that banking and borrowing allow firms to smooth emissions. Under uncertainty, Schennach (2000) shows the permits price may rise at a rate less than the discount rate and new public information may cause jumps in the price and emissions paths, among other major contributions.

This article builds on the intertemporal emissions trading literature with market imperfections. It aims at filling the gap in the literature between the pros and cons of authorizing banking and borrowing in permit trading programs, a topic which is typically not enough debated when deciding to adopt such an environmental regulation system. Against this background, it attempts to shed some light on the ability of a large agent to move dynamic markets when permits are grandfathered.

Liski & Montero (2005b) study the effect of market power on the equilibrium of a permits market by introducing a large potentially dominant and a competitive fringe. Based upon two cases, their analysis reveals first that the large agent might manipulate the market by banking allowances when it owns all the stock of permits and second when the fringe receives all the stock of permits, the large agent has an incentive to exchange permits at the competitive price and to build a permits bank for the next period. While previous papers restricted their analysis to banking only[2], both banking and borrowing are allowed without restrictions in a continuous time setting.

The model brings to the regulatory economics literature a realistic description of relationships between agents on a tradable permits market with information asymmetry. As Liski & Montero (2005b) did not impose a par-

[1] For an exhaustive literature review on permits trading and market power, see Petrakis & Xepapadeas (2003).

[2] This was mainly due to the fact that no major international agreement on greenhouse gases allows borrowing to a full extent to date (personal contacts with M. Liski).

ticular game structure, I adopt a Stackelberg game structure that allows to deal with specific interactions between two types of agents: a leader with an informational advantage associated to a large agent, and a follower associated to a competitive fringe.

The market imperfection arises from the free distribution of permits on the basis of past emissions, while the product market is assumed to remain competitive[3]. I explicitly include the Hotelling conditions[4] that must apply if permits are considered as an exhaustible resource.

The paper unfolds as follows: first, I describe the institutional environment of current permit trading programs, namely the Kyoto Protocol (KP) and the European Union Emissions Trading Scheme (EU ETS); second I derive in a benchmark case an expression for market power; third I develop the Stackelberg game; fourth I suggest an optimal allocation criterion to correct for these market imperfections[5].

2 Description of the Institutional Environment

In this section, I describe how the model hinges on critical design issues of existing international emissions trading schemes, namely the KP and the EU ETS. I also attempt to provide a balanced picture of the EU ETS and KP market power concerns.

2.1 The Kyoto Protocol

The question of the Kyoto Protocol as an "unfinished business" is often evoked. Very heterogenous sectors were included under the same regulation, which could be detrimental to find the right method to allocate permits depending on price elasticities between sectors.

The intra-industry structure adopted in this paper may be seen as a simplification of the KP. Yet it may propose useful policy recommendations when dealing with such an international scheme. I focus on the negotiation phase, the special case of Russia and the prospective use of banking and borrowing.

[3]For the distinction between permits market and industry structure imperfections, see Sartzetakis (1997) and Sartzetakis (2004)

[4]Namely the exhaustion and terminal conditions.

[5]See Eyckmans & Coenen (2006) for an introduction to the debate.

2.1.1 Negotiation phase

In the context of the KP, the case of countries supplied with allocations in excess of their actual needs has been coined as *Hot Air* in the literature[6]. The distribution of a large number of permits to Former Soviet Union (FSU) and Eastern Europe countries (Russia, the Ukraine forming two thirds) may be seen indeed as an imperfection of the KP, as those countries were given generous allocations to foster agreement during the first phase (2008-2012). Market power concerns arise as industrial firms may benefit from the gap between the initial permits allocation (based on 1990 production levels) and their real emission needs in 2008 (after a period of recession), and the use of these permits surpluses remains unclear.

This situation emerged as a conflict between the internal and the external consistency of the permits market:

- the *internal* consistency refers to the situation where agents freely receive or bid for permits according to their real needs. The regulator may be interested however in distributing more permits to a country than strictly needed (according to business as usual emissions or a benchmark for instance) in order to ensure participation to the permits market[7]. As a consequence, one agent may achieve a dominant position which in turns threatens the efficiency of the permits market itself.

- the *external* consistency of the permits market is linked to the broader debate of climate change as the purchase of a "global public good"[8]. This altruistic view embodies the notions of "burden sharing" or "differentiated responsibilities" attached to the KP, whereby developed countries agree to spend a higher income share on fighting climate change than developing countries[9].

Those conflicting views undermine the negotiation of the cap, which is fixed at a suboptimal level compared to what would be needed to minimize the total damage to the environment. Greenhouse gases (GHG) emission targets under the KP represents a mere 5% reduction below 1990 levels. Now if early movers like EU countries are willing to ratchet down the cap, little

[6]See Baron (1999), Burniaux (1999), Bernard *et al.* (2003), Bohringer & Loshel (2003), Holtsmark (2003).

[7]Such negotiation with Russia was determinant for the KP to enter into force on 16/02/05

[8]See Guesnerie (2006).

[9]Note that the implicit assumptions of the existence of such an Environmental Kuznets Curve (the environment is a superior good and environmental regulation becomes stricter through time at higher levels of GDP per capita) is left out of the debate.

progress can be achieved without luring in major players like the USA, India and China. Thus, many difficulties arise to pierce the "veil of uncertainty" around international negotiation[10].

Uncertainty also affects trading rules that will be effectively implemented at the international level. As Klepper & Peterson (2005)[11] put it:"*The Kyoto Protocol and its related decisions do not explicitly state who is actually supposed to be trading. Probably we will observe both government and firm trading. Under the former, market power might indeed become a relevant issue*".

The fact that setting up a permits market might give some countries the opportunity to draw a financial advantage without a direct environmental gain (i.e. in the absence of effective emissions abatement) might be puzzling. But as stated in Maeda (2003)[12], "*[This debate] seems misguided because it focuses on the political importance of the issue, rather than addressing it from an economic perspective.*"

Overall, the hypothesis that generous allocations that broaden the scope of a cap-and-trade program might also give birth to dominant positions shall not be neglected. This leads me to comment the case of Russia more in depth.

2.1.2 Will Russia be a net seller of permits?

Russia seems the best example to investigate potential market power within the KP according to Korppoo *et al.* (2006)[13]: "*Given the collapse of its emissions in the course of its economic transition, Russia is the country with by far the largest potential surplus of emission allowances for sale under the Kyoto international trading mechanisms. It is also generally considered to be the country with the greatest potential for continuing emission-reducing improvements in energy efficiency. Indeed, in the first commitment period under the Kyoto Protocol it could be described as the Saudi Arabia of the emerging carbon market, with the potential to try to manipulate the market through strategic decisions as to when and how it releases it surplus - if there are buyers willing to deal.*"

Empirical evidence gathered by Grubb (2004), Liski & Montero (2005a)[14] and Korppoo *et al.* (2006) suggest Russia will be a net seller of allowances

[10] See Kolstad (2005).

[11] p.207

[12] p.295

[13] p.2

[14] Based on the MIT-EPPA database that aggregates FSU countries.

during the first phase of the KP. Different projections for Russian CO_2 emissions and surplus are detailed in Tables 1 and 2.

Source	Year of Estimate	Percentage of 1990 Levels	Period
Russian Energy Strategy	2000	76-93	2012
IEA[a] World Energy Outlook	2004	72	2008-2012
CEPA[b c]	2004	75	2008-2012

Table 1: A Survey of Projections for Russian Carbon Dioxide Emissions. *Source*: adapted from Korpoo et al. (2006)

[a]International Energy Agency.
[b]Cambridge Economic Policy Associates.
[c]Scenario with a 2% energy intensity reduction.

Source	Year of Estimate	Size of the surplus[a]	Period
Russian Ministry of Economic Development and Trade[b]	2003	408-545	2008-2012
Russian Forecast to the UNFCCC[c]	2003	456-913	2008-2012
CEPA	2004	400	2008-2012
Klepper-Peterson	2005	410	2010
Bohringer et al.	2006	246[d]	2008-2012

Table 2: A Survey of Projections for Russia's Surplus under the KP. *Source*: author

[a]In million tonnes of carbon equivalent (MtCe).
[b]adapted from Korpoo et al. (2005)
[c]adapted from Korpoo et al. (2005)
[d]$MtCO_2$

The key finding in Table 1 is that under all scenarios Russia would meet its Kyoto targets, as its CO_2 emissions projections consistently hit below 1990 levels. The room for interpretation of Table 2 is limited by the wide variation in surplus estimates with a lowest value of 246 $MtCO_2$ found by Bohringer *et al.* (2006) and, as expressed above, by the current absence of clearly defined international trading rules to monetize such a surplus. Further projections regarding Russia's own energy demand *after* the first period of the KP are neeeded to determine whether Russian industrial firms might be able to affect negatively other members' marginal abatement costs.

2.1.3 Prospective use of banking and borrowing in the KP

This section offers a description of the possible use of banking borrowing in the KP. On the one hand, provisions on banking are explicited by Klepper & Peterson (2005)[15]: "*Assigned amount units (AAUs) resulting from the Kyoto commitment can be banked without a time constraint. Credits from Joint Implementation (JI) or Clean Development Mechanism (CDM) can be banked up to a limit of , respectively, 2.5% and 5% of a Party's initial assigned amount. Sink credits can not be banked*".

On the other hand, implicit provisions on borrowing may be found in the United Nations Framework Convention on Climate Change (UNFCCC (2000)) report[16]. As explained by Newell *et al.* (2005)[17]: "*International climate policy discussions have implicitly included borrowing within possible consequences for noncompliance under the Kyoto Protocol, through the pay-back of excess tons with a penalty (i.e., interest).*"

As stated earlier, this issue remains unclear and reveals a lack of a specific debate on the pros and the cons to allow banking and / or limited borrowing, if not a lack of theoretical grounding.

2.2 The European Union Emissions Trading Scheme

Here I draw comments on two critical aspects of the EU ETS. First, I deal with possible design flaws in the allocation of permits that might pave the way for dominant positions during the first phase. Second, I provide an overview of the prospective use of banking and borrowing.

2.2.1 Over-allocation or relative success?

The EU ETS gently constrains emissions (8% reduction for EU-15) so as to start with a low carbon price. Yet the public debate has shifted toward a possible over-allocation of permits during the first phase. The production decisions of private actors are under scrutiny: do permits surpluses constitute a relative success (i.e. firms have reduced their emissions above projected levels) or an imperfection in the design of the system?

[15] p.295
[16] paragraph II.XV
[17] p.149

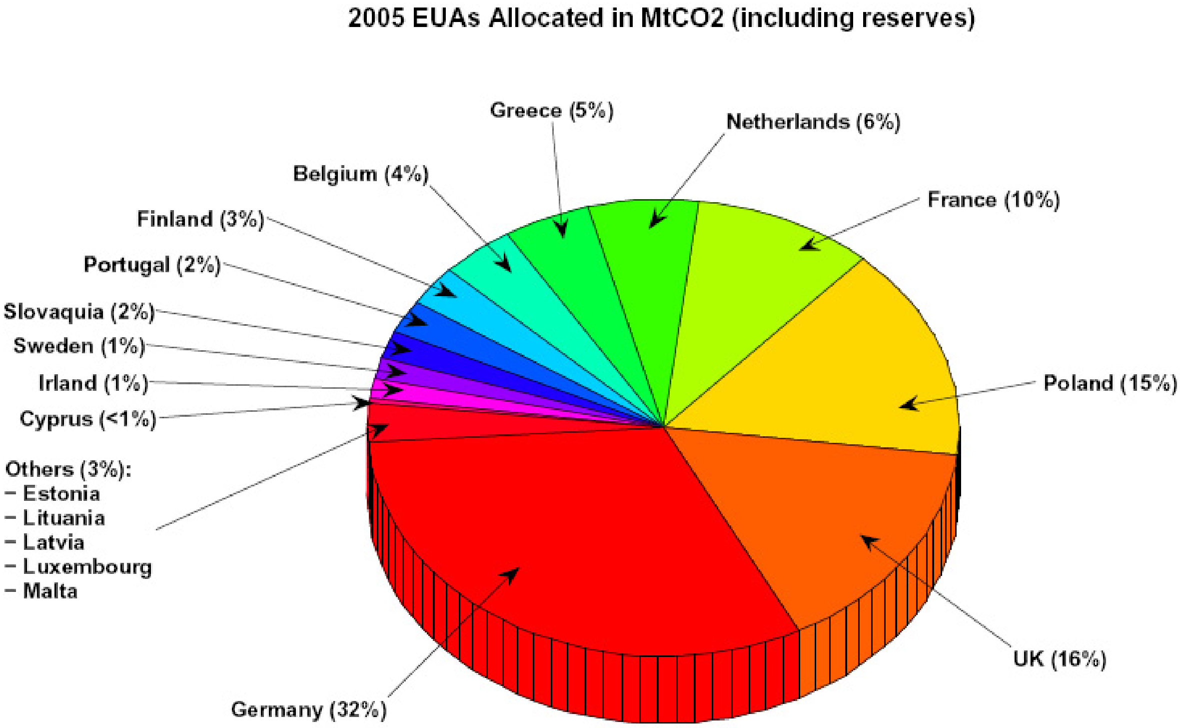

Figure 1: EU ETS National Allocation Plans - Phase 1 (2005-2007) *Source*: Caisse Des Depots et Consignations (CDC, 2006)

Figure 1 represents the repartition of 2005 European Union Allowance Units (EUAs) among countries, where Germany, Poland and the UK stand out as the most important actors by totalling about two thirds of the total allowances. Data is taken from CDC (2006)[18]. While it is not our goal to comment on the structure of the European carbon market here, it seems interesting to look at the possible surplus those countries were endowed with.

Figure 2 depicts the 2005 reported emissions and, if any, the size of the surplus. The sum of the two bars is equivalent to the 2005 allocation of permits for a given country. It reflects a wide variety of cases among market participants as a bulk of countries (France, the Netherlands, Finland, Slovaquia, Sweden) was able to build a permits surplus above 15%, while Greece is short of permits. Surpluses also reflect in a limited amount reserves for new entrants, which are included in the data used .

Table 3 takes a closer look at the allowances surpluses in million tonnes of CO_2 and in percentage of the allocation. Its main finding lies in the fact that most countries seemed to favor generous allocations during the first phase of the EU ETS[19]. The biggest player, Germany does not seem to be in a position to exert market power with little more than 5% excess allowances. The surplus of Poland need not be overstated either since the use of 10% of allowances is missing in the Community Independent Transaction Log (CITL) administered by the European Commission. Germany, UK, and Portugal form a group of countries where the regulator strived to allocate optimally. On the contrary, stricter emissions reductions were enforced in the case of Ireland and Greece.

How could one explain those contrasting patterns in actual emissions for EU ETS participants in 2005? Part of the answer may be found in the decision making process within each National Allocation Plan (NAP). Godard (2003) and Godard (2005) describe the logic behind the French NAP when allocating shares of recent emissions baselines: non-electric utilities were supplied with their projected need in permits, while electric utilities were more constrained. This situation may be justified by the perceived abatement potential of the electricity industry, but it reveals overall the necessary arbitrages to be made due to sector heterogeneity and a stringent cap.

Due to a lack of data availability from 2004 onwards, it appears difficult to

[18] *Tendances Carbone* is published by the French Caisse des Depots and is available at <http://www.caissedesdepots.fr/>, accessed on November, 24th

[19] Apart from the EU ETS, there is a need to be cautious here with the notions of "over allocating" and conversely "under-allocating" permits depending on the country. Their meaning depends on the reference point (business as usual plus some abatement for instance). If other trading schemes implement per capita distribution for instance, it may appear less relevant to talk about "over allocation".

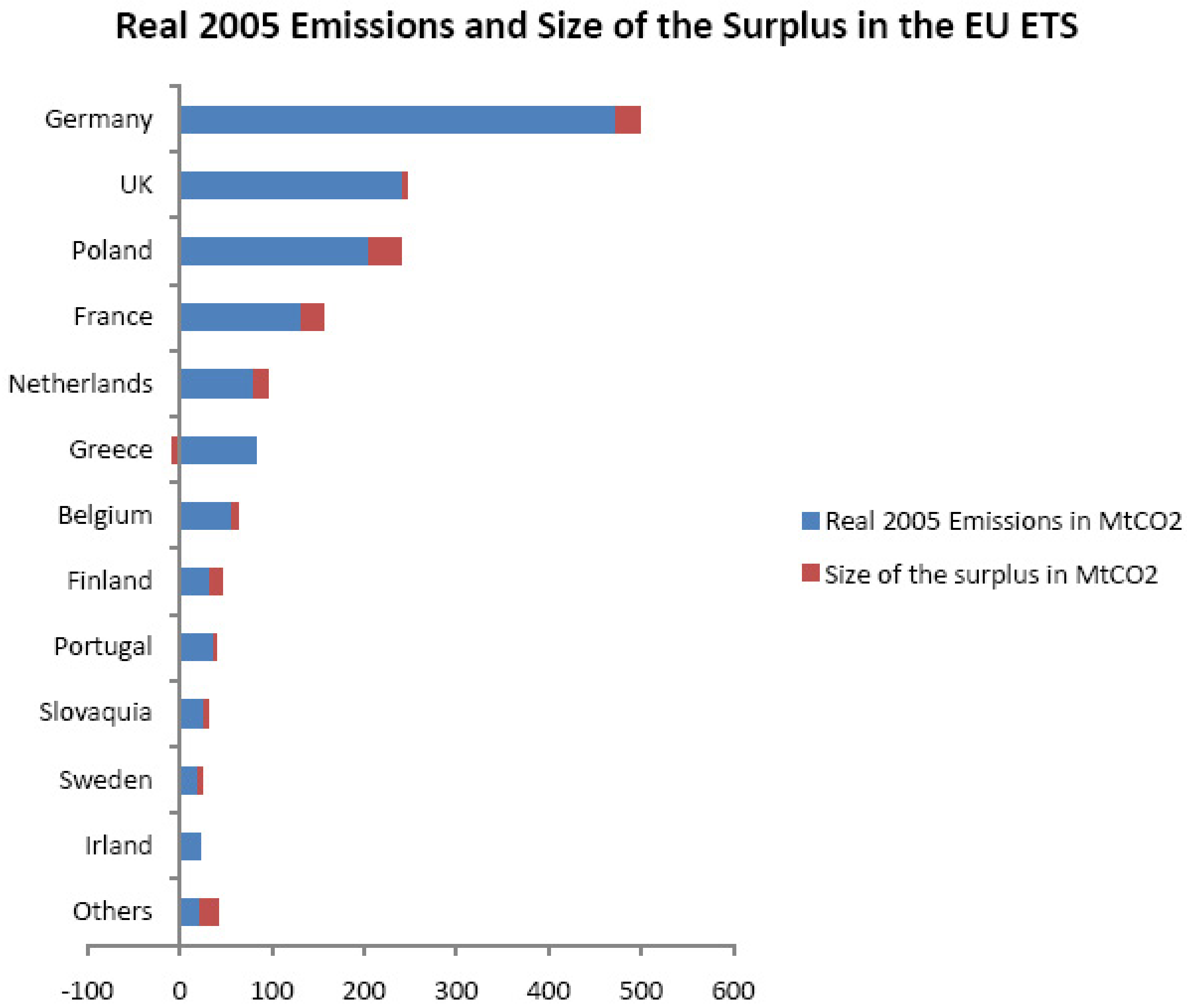

Figure 2: EU ETS 2005 Reported Emissions and Size of the Surplus *Source*: CDC (2006)

Country[a]	Size of the Surplus[b])	Percentage of Allocation
Finland	12,4	27,3
Slovaquia	5,3	17,4
Sweden	3,8	16,5
France	24,3	15,6
Netherlands	14,9	15,6
Poland	33,7[c]	14,1
Belgium	7,5	11,9
Germany	25,3	5,1
Portugal	1,8	4,7
UK	2,9	1,2
Ireland	-0,1	-0,4
Greece	-8,6[d]	-11.6
Others	>20	>47,5

Table 3: Size of the Surplus among EU ETS Participants in 2005. *Source*: CDC (2006)

[a] Data for Cyprus is missing.

[b] European Union Allocation in MtCO_2

[c] This surplus needs to take into account 10% of allowances whose emissions have not been reported yet.

[d] A negative value refers to an actual excess in the level of emissions with respect to the cap.

provide a more precise characterization of the room for market power at the sectoral level. For French installations subject to the Directive 2003/87/CE, an estimation based on 1,402 installations totalling 185,3 $MtCO_2$ taken from the Register for Polluting Emissions (iREP)[20] reveals almost 50% of permits were distributed to four players, and the first ten permits holder sum up to 60% of permits allocation. Each of this big players might exert a dominant position on its own sector if permits are distributed freely based on recent emissions, as modelled in this paper.

2.2.2 Prospective use of banking and borrowing in the EU ETS

Member states may allow banking without restriction. But this possibility to carry over EUAs from from 2005-2007 to 2008-2012 in the EU ETS is very limited in practice. Only France and Poland have allowed it to a certain extent, i.e. permits that were bought cannot be banked. Besides, only "green" firms that have effectively reduced emissions may bank allowances in Poland.

This section provided an overview of two major permits market along with their allocation rules. This background information is used as the basis for the modelling of a differential game with hierarchical play in the paper.

3 The Model

This section details the features of the model. First, I explain the design of the cap-and-trade program. Second, I examine the industry and information structures. Third, I define an intertemporal emissions trading constraint. Fourth, I express the Hotelling conditions. Finally, I explicit the properties of the abatement cost function.

3.1 Design of the Cap-and-Trade Program

The regulator sets a cap $\overline{E}$ on emissions of a given pollutant that corresponds to a specific environmental goal. The fix endowment is therefore exogenous to the model, and may be broken down into individual permits allocation $\overline{e}_i$ mandatory for each agent i.

Agent $[i = 1]$ is a large polluting agent, who is initially allocated a large number of permits. Agents $[i = 2, \dots N]$ aggregate many small polluting agent, who sare assumed to be comparatively smaller permits-holders. The

[20]The iREP is monitored by the Minister of the Environment and displays public information at <http://www.pollutionsindustrielles.ecologie.gouv.fr/IREP/index.php> (accessed on November, 24th 2006).

premise of the paper is that the large agent might be able to exercise market power.

Permits are distributed freely on the basis of recent emissions[21]. Agents may bank and borrow permits without restrictions. We do not include the effects of allowing a safety valve[22] in the model.

3.2 Industry Structure

This partial equilibrium model features an intra-industry permit market in an homogenous single good economy. In what follows, I tend to neglect the interaction with the output market. An agent may be either a country, a firm or a cartel[23]. The competitive market price is determined by fringe agents' abatement costs.

3.3 Information Structure

I model a differential game[24] played in continuous time where all players have the possibility of influencing the rate of change of the permits bank through the choice of their current actions. It is therefore assumed that they adopt a Markovian strategy.

The common knowledge includes the fact that all players need to comply to the environmental constraint exogenously set by the regulator. The game unfolds in two steps. First, I derive the follower's reaction function to any action announced by the leader through fringe agents' cost minimization

[21]See Ellerman & Wing (2003) for a review concerning the use of projections, benchmarking and intensity targets. While it is beyond the scope of this paper to study the relative merits of grandfathering and auctioning, theoretical analyses stress the superiority of auctioning as in Jouvet *et al.* (2005). In the view of the Public Choice Theory, free allocation of permits may also be seen by some firms as a means to extract more permits as a scarcity rent, and therefore lobbying takes place. But it is also imposes liabilities on firms that will be reflected in their balance sheets. As highlighted by Raymond (1996), initial permits allocation reveals social norms embedded by newly created permits. The free distribution of permits may be seen as an entitlement over an environmental resource. As conceptions evolve and auctioning might become predominant, the question arises whether the probability of achieving a dominant position will increase or decrease.

[22]A safety valve may be defined as an hybrid instrument to limit the cost of capping emissions at some target level whereby the regulator offers to sell permits in whatever quantity at a pre-determined price.

[23]For instance, within the KP permits may be exchanged party-to-party, but also firm-to-firm if Annex B members delegate this ability to private actors. In the third case, collusive behaviours may appear either between parties or between firms. (Liski & Montero (2005b))

[24]See Dockner *et al.* (2000) for an overview of diffential games.

problem at the competitive price. Second, I observe how the the leader might exercise market power as large agent integrates the reaction function into his own cost minimization problem, and decides how to adjust his emissions level. I hold all other parameters constant[25].

3.4 Intertemporal Emissions Trading

Let $B_i(t)$ be the permits bank, with $B_i(t) > 0$ in case of banking and $B_i(t) < 0$ in case of borrowing.

Any change in the permits bank is equal to the difference between $\overline{e}_i(t)$ and $e_i(t)$, respectively agent's i permits allocation and his emission level at time t. The banking borrowing constraint may be written as:

$$\dot{B}_i(t) = \overline{e}_i(t) - e_i(t) \tag{1}$$

with $B_i(0) = 0$ and $B_i(T) \geq 0$ as banking and borrowing are assumed to be always allowed[26].

3.5 Hotelling Conditions

Notwithstanding differences between a permit and an exhaustible resource[27], it is assumed in the literature that the Hotelling conditions for exhaustible resources must apply on a permits market. Consequently, the terminal and exhaustion conditions are detailed below.

3.5.1 Terminal Condition

Let $[0, T]$ be the continuous time planning horizon[28]. At time T, cumulated emissions must be equal to the sum of each agent's depollution objective and

[25] For instance, agents do not incur information costs.

[26] See Rubin (1996), p. 272

[27] According to Liski & Montero (2006) (p.3), the following differences may be highlighted. First, in a permits market with banking, the market may remain after the exhaustion of the bank; while the market of a non-renewable resource vanishes after the last unit extraction. Second, permits extraction and storage costs are equal to zero; while those costs are generally positive for a non-renewable resource. Third, the demand for an extra permit usually comes from a derived demand of other firms that also hold permits; while the demand for an extra unit of a non-renewable resource comes more often from a derived demand of another actor (e.g., a consumer).

[28] This planning period seems appropriate for a theoretical study of intertemporal emissions trading. Alternative time settings including distinct phases may be found in Montero & Ellerman (1998), Schennach (2000) or Ellerman & Montero (2002), but they reflect the specific requirements of the *Acid Rain Program* (USA).

therefore to the global cap $\overline{E}$ set by the regulator[29]:

$$\int_0^T \sum_{i=1}^N e_i(t)\mathrm{d}t = \sum_{i=1}^N \overline{e}_i = \overline{E} \tag{2}$$

3.5.2 Exhaustion Condition

At time T, there is no more permit in the bank (either stocked or borrowed):

$$\sum_{i=1}^N B_i(T) = 0 \tag{3}$$

Those conditions ensure that agents gradually meet their depollution objective so that the marginal cost of depollution is equalized in present value over the time period, and the permits bank clears in the end.

3.6 Abatement Cost Function

Let $C_i[e_i(t)]$ be the abatement cost function[30] incurred by agent i in order to comply with his permits allocation $\overline{e}_i$. $C_i[e_i(t)]$ is defined on $\Re^2$ in $\Re$ continuous and is of class $C^2[0;T]$, i.e. twice continuously differentiable. The classical assumption[31] of strictly increasing abatement costs leads $C_i[e_i(t)]$ to be convex, with $C_i'[e_i(t)] < 0$ and $C_i''[e_i(t)] > 0$. I can set $C_i[e_i(0)] = 0$.

Agent's i marginal abatement costs (MAC) are associated with a one-unit reduction from his emission level e_i at time t and are noted $-C_i'[e_i(t)] > 0$. At the equilibrium of a permits market in a static framework[32], price-taking agents adjust emissions until the aggregated MAC is equal to the price P at time t:

$$P_t = -C_i'[e_i(t)] \tag{4}$$

Thus, at the equilibrium, there is no arbitrage for price-taking agents.

[29] See also Leiby & Rubin (2001), p. 231.

[30] Compared to a situation where profits are unconstrained, abatement costs appear in order to meet the emission cap $\overline{e}_i$.

[31] Stated first by Montgomery (1972). The conditions given by Leiby & Rubin (2001) include the output $q(t)$ where $C_i[q_i(t), e_i(t), t]$ is strongly convex with $C_i'[q_i(t)] > 0$ and $C_i''[q_i(t)] > 0$. Properties of non-convex abatement cost functions may be found in Godby (2000).

[32] See Hahn (1984).

4 Benchmark Case

In order to reveal the conditions under which the large agent may exercise market power, I develop in the first section a benchmark case where the large agent receives all the stock of permits.

4.1 Optimization program

The expression of market power may be derived straightforward when the large agent owns all the stock of permits, and directly integrates the competitive price into his maximization program. In this setting, fringe agents' emissions come from trading with the large agent. To simplify notations in this section, let $y_1(t)$ be the number of permits distributed to the large agent.

The large agent behaves as follows:

$$\begin{cases} min \displaystyle\int_0^T e^{-rt}\Big\{C_1[e_1(t)] + P_t\ y_1(t)\Big\}\ \mathrm{d}t \\ \displaystyle\int_0^T e_1(t)\ \mathrm{d}t = \overline{E} - \int_0^T \sum_{i=2}^N e_i(t)\ \mathrm{d}t \\ P_t = -C_i'\left[\displaystyle\sum_{i=2}^N e_i(t)\right] \\ y_1(t) = \displaystyle\sum_{i=2}^N e_i(t) \end{cases}$$

I form the Lagrangean with $e_1(t)$ and $e_i(t)$ as control variables, and $\lambda(t)$ as a multiplier:

$$\begin{aligned} L = & \int_0^T e^{-rt}\left\{C_1[e_1(t)] - C_i'\left[\sum_{i=2}^N e_i(t)\right]\sum_{i=2}^N e_i(t)\right\}\ \mathrm{d}t \\ & +\lambda(t)\left[\overline{E} - \int_0^T e_1(t)\mathrm{d}t - \int_0^T \sum_{i=2}^N e_i(t)\mathrm{d}t\right] \end{aligned}$$

The first-order conditions are:

$$\begin{aligned} \frac{\partial L}{\partial e_1(t)} &= C_1'[e_1(t)] - \lambda(t) = 0 \\ \frac{\partial L}{\partial e_i(t)} &= -C_i''\left(\sum_{i=2}^N e_i(t)\right)\sum_{i=2}^N e_i(t)\ - C_i'\left(\sum_{i=2}^N e_i(t)\right) - \lambda(t) = 0 \end{aligned}$$

Replacing $\lambda(t) = C_1'[e_1(t)]$ in the second equation, dropping the time subscript for notational ease and rearranging terms, I get:

$$-C_i''\left(\sum_{i=2}^{N} e_i\right)\sum_{i=2}^{N} e_i \ - C_i'\left(\sum_{i=2}^{N} e_i\right) - C_1'(e_1) = 0$$

$$-C_1'(e_1) = C_i''\left(\sum_{i=2}^{N} e_i\right)\sum_{i=2}^{N} e_i \ + C_i'\left(\sum_{i=2}^{N} e_i\right)$$

$$-C_1'(e_1) = C_i'\left(\sum_{i=2}^{N} e_i\right)\left(1 + \frac{C_i''}{C_i'}\sum_{i=2}^{N} e_i\right)$$

$$-C_1'(e_1) = P\left[1 + \varepsilon_i \sum_{i=2}^{N} e_i\right]$$

with ε_i defined as fringe agents' elasticity:

$$\varepsilon_i = \frac{C_i''(e_i)}{C_i'(e_i)} = \frac{\frac{\mathrm{d}C_i'}{\mathrm{d}e_i}}{\frac{\mathrm{d}C_i}{\mathrm{d}e_i}} = \frac{\mathrm{d}C_i'}{\mathrm{d}e_i}\,\frac{\mathrm{d}e_i}{\mathrm{d}C_i} = \frac{\mathrm{d}C_i'}{\mathrm{d}C_i}$$

ε_i measures the relative variation between an additional unit of emission and the acceleration of marginal cost. A high elasticity (in absolute value) induces a strong link between the two variables.

4.2 Market Power Condition

Market power is function of fringe agents' elasticity and of the large agent's number of permits:

$$\varepsilon_i \ \sum_{i=2}^{N} e_i(t) = \varepsilon_i \ y_1(t) \tag{5}$$

Due to the convexity assumption, fringe agents' elasticity is negative, and reveals the possibility for the leader to affect negatively fringe agents' behaviour.

The large agent's MAC is therefore *lower* than under perfect competition, since he enjoys a dominant position.

Overall, the large agent may be characterized as a net gainer and fringe agents as net losers in this setting.

5 Fringe Agents' Reaction Function

The firs step of the game consists in forming the strategy of the fringe. Fringe agents choose their optimal emissions level according to the possibility to bank and borrow permits in constraint (1). The cost minimization program may be written as follows:

$$\begin{cases} \min_{e_i} \int_0^T e^{-rt} \left\{ C_i[e_i(t)] + P(t)\ [e_i(t) - \overline{e}_i(t)] \right\} \mathrm{d}t \\ \dot{B}_i(t) = \overline{e}_i(t) - e_i(t) \\ B_i(0) = 0,\ B_i(T) \geq 0 \\ C_i[e_i(0)] = 0 \end{cases}$$

where the expression $[e_i(t) - \overline{e}_i(t)]$ represents the number of permits bought (> 0) or sold (< 0).

I write the corresponding current-value Hamiltonian and first-order optimality conditions:

$$H(B_i(t), e_i(t), \lambda(t), t) = \{C_i[e_i(t)] + P(t)\ [e_i(t) - \overline{e}_i(t)]\} - \lambda(t)[\overline{e}_i(t) - e_i(t)]$$

$$\frac{\partial H}{\partial e_i(t)} = 0 :\ P(t) = -C_i'[e_i(t)] + \lambda(t) \tag{6}$$

$$\dot{B}_i(t) = \frac{\partial H}{\partial \lambda(t)} = 0 : \dot{B}_i(t) = \overline{e}_i(t) - e_i(t) \tag{7}$$

$$\dot{\lambda}(t) - r\lambda(t) = -\frac{\partial H}{\partial B_i(t)} = 0,\ \lambda(T)B_i(T) = 0 \tag{8}$$

Note that the transversality condition in (8), required to meet the exhaustion condition (3), is a sufficient optimality condition. The bank has no scrap value at the end of the period.

It can be infered from (8) that $\lambda(t) = \lambda(0)e^{rt}$. When fringe agents build a permits bank in terminal period, $\{B_i(T) > 0, \lambda(T) = 0, \lambda(t) = 0\}$. The reaction function is therefore equal to the static equilibrium condition (4) where fringe agents equalize their MAC with the permits price.

Conversely, the reaction function is equal to (6) when fringe agents do not keep permits in the bank in terminal period and the constraint on λ is binding.

I now turn to the large agent's behaviour and to how he integrates the two possible cases of reaction function into his own optimization program.

6 Behaviour of the Large Agent

6.1 Optimization program

The large agent adjusts strategically his optimal emissions levels according to its initial allocation $\overline{e}_1$ as expressed by (2) and the banking borrowing constraint (1). The cost minimization program for agent $[i = 1]$ is:

$$\begin{cases} \min\limits_{e_1} \displaystyle\int_0^T e^{-rt} \left\{ C_1[e_1(t)] + P_t \; [e_1(t) - \overline{e}_1(t)] \right\} \; \mathrm{d}t \\ \dot{B}_1(t) = \overline{e}_1(t) - e_1(t) \\ \overline{E} = \displaystyle\int_0^T e_1(t)\mathrm{d}t + \int_0^T \sum_{i=2}^{N} e_i(t)\mathrm{d}t \\ B_1(0) = 0, \; B_1(T) \geq 0 \\ C_1[e_1(0)] = 0 \end{cases}$$

6.2 First case

Replacing P_t by (4), the large agent's optimization program becomes:

$$\begin{cases} \min\limits_{e_1} \displaystyle\int_0^T e^{-rt} \left\{ C_1[e_1(t)] - C_i'[e_i(t)] \; [e_1(t) - \overline{e}_1(t)] \right\} \; \mathrm{d}t \\ \dot{B}_1(t) = \overline{e}_1(t) - e_1(t) \\ \overline{E} = \displaystyle\int_0^T e_1(t)\mathrm{d}t + \int_0^T \sum_{i=2}^{N} e_i(t)\mathrm{d}t \\ B_i(0) = 0, \; B_i(T) \geq 0 \\ C_1[e_1(0)] = 0 \end{cases}$$

Assuming fringe agents are homogenous, I write $\sum_{i=2}^{N} e_i(t) = (N-1)e_i(t)$ and replace the emissions constraint (2) into the objective function:

$$\begin{cases} \min\limits_{e_1} \displaystyle\int_0^T e^{-rt} \left\{ C_1[e_1(t)] - C_i' \; \left[\frac{\overline{E} - e_1(t)}{N-1} \right] \; [e_1(t) - \overline{e}_1(t)] \right\} \; \mathrm{d}t \\ \dot{B}_1(t) = \overline{e}_1(t) - e_1(t) \\ B_i(0) = 0, \; B_i(T) \geq 0 \\ C_1[e_1(0)] = 0 \end{cases}$$

I form the corresponding current-value Hamiltonian with $e_1(t)$ as a control variable, $B_1(t)$ as a state variable, and $\mu(t)$ as a co-state variable:

$$H(B_1(t), e_1(t), \mu(t), t) =$$

$$C_1[e_1(t)] - C_i' \left[\frac{\overline{E} - e_1(t)}{N-1} \right] \; [e_1(t) - \overline{e}_1(t)] + \mu(t)[\overline{e}_1(t) - e_1(t)]$$

Assuming the existence of an interior solution, necessary optimality conditions include:

$$\frac{\partial H}{\partial e_1(t)} = 0 :$$

$$C_1'[e_1(t)] + \frac{1}{N-1} C_i'' \left[\frac{\overline{E} - e_1(t)}{N-1}\right] [e_1(t) - \overline{e}_1(t)] - C_i' \left[\frac{\overline{E} - e_1(t)}{N-1}\right] - \mu(t) = 0 \tag{9}$$

$$\dot{B}_1(t) = \frac{\partial H}{\partial \mu(t)} = 0 : \;\; \dot{B}_1(t) = \overline{e}_1(t) - e_1(t) \tag{10}$$

$$\dot{\mu}(t) - r\mu(t) = -\frac{\partial H}{\partial B_1(t)} = 0, \;\; \mu(T)B_1(T) = 0 \tag{11}$$

If $\{B_1(T) > 0, \mu = 0\}$, the large agent also builds a permits bank in terminal period. From (9), it is possible to identify an analogous version of market power condition (5):

$$-C_1'[e_1(t)] = -C_i' \left[\frac{\overline{E} - e_1(t)}{N-1}\right] \left[1 + \frac{1}{N-1} \frac{C_i''}{C_i'} [e_1(t) - \overline{e}_1(t)]\right]$$

$$-C_1'[e_1(t)] = P(t) \left[1 + \frac{1}{N-1} [e_1(t) - \overline{e}_1(t)]\right]$$

In comparison with the benchmark case where the large agent owns all the stock of permits, in the case where both types of agents keep a permits bank in the end, the large agent is able to affect fringe agent's MAC through the number of permits he holds in excess of his emissions.

6.3 Second case

In the second case, replacing P_t by (6), the large agent's optimization program becomes:

$$\begin{cases} \min\limits_{e_1} \displaystyle\int_0^T e^{-rt} \left\{C_1[e_1(t)] - \{C_i'[e_i(t)] + \lambda(t)\} [e_1(t) - \overline{e}_1(t)]\right\} \, \mathrm{d}t \\ \dot{B}_1(t) = \overline{e}_1(t) - e_1(t) \\ \overline{E} = \displaystyle\int_0^T e_1(t)\mathrm{d}t + \int_0^T \sum_{i=2}^N e_i(t)\mathrm{d}t \\ B_i(0) = 0, \;\; B_i(T) \geq 0 \\ C_1[e_1(0)] = 0 \end{cases}$$

Rearranging as above and setting $\{B_i(T) = 0, B_1(T) = 0, \lambda(t) > 0, \mu(t) > 0\}$ yields:

$$-C_1'[e_1(t)] + \mu(t) = -C_i' \left[\frac{\overline{E} - e_1(t)}{N-1} \right] \left[1 + \frac{1}{N-1} \frac{C_i''}{C_i'} \left[e_1(t) - \overline{e}_1(t) \right] \right] - \lambda(t)$$

This condition means that when fringe agents do not build a permits bank in the end, the large agent is still able to affect negatively fringe agent's MAC. Both values of $\mu(t)$ and $\lambda(t)$ are known. For the large agent, the shadow value of a unit of emission in the bank measures the marginal utility of the state at time t along the optimal trajectory. For fringe agents, $\lambda(t)$ reflects the highest hypothetical price at which they would be willing to pay for an additional permit at time t.

However, the spectre of a large agent achieving a market power position may be averted by a careful design of the cap-and-trade program. This leads to the next section where I give hints about the goals of the regulator.

7 Critical Perspectives on Permits Allocation

I examined so far how the distribution of a large number of permits to one agent according to current emissions may foster the emergence of market power.

Now, I turn to the determination of the number of permits that it is optimal to distribute to the large agent without introducing distortions from the competitive equilibrium.

As in Eshel (2005) who demonstrates how the regulator might distribute permits in order to restore the overall economic efficiency of the permits market, I use first comparative statics to examine the change in agents' behaviour induced by marginal changes in the allocation of permits. Then, I adopt the regulator's viewpoint (associated to the social planner) to correct the market imperfection inherited from initial allocation in the previous example.

7.1 Comparative Statics

The effects of distributing an additional permit to the large agent will be captured by $\overline{e}_1$. In the case where $\mu = 0$, differentiating the optimality conditions (9) to (11) with respect to $\overline{e}_1$ gives:

$$\frac{\partial e_1^*}{\partial \overline{e}_1} = -\frac{1}{N-1} C_i'' \left[\frac{\overline{E} - e_1(t)}{N-1} \right]$$

The distribution of an additional permit to the large agent directly affects fringe agents' emissions level through a variation of their marginal cost. This result also holds in constrained regime. It may be infered optimal abatement costs levels will only be reached in a "no market power" situation.

7.2 Social Welfare

In this model, the goal of a welfare-maximizing social regulator consists in *minimizing* abatement costs of the large agent and fringe agents respectively, and the consumer's surplus *losses* from trade in the output S_t. The regulator must distribute no more than $\overline{e}_1(t)^*$ to the large agent.

The optimization program of the regulator is:

$$\min_{e_1-\overline{e}_1} \int_0^T e^{-\rho t}\Big[C_1[e_1(t)] + P_t[e_1(t) - \overline{e}_1(t)]\Big]\mathrm{d}t$$

$$+\int_0^T e^{-\rho t}\Big[C_i[e_i(t)] + P(t)[e_i(t) - \overline{e}_i(t)]\Big]\mathrm{d}t + \int_0^T e^{-\rho t} S_t \mathrm{d}t$$

where ρ represents the time preference coefficient.

The change of a one-unit allocation of permit on the large agent and fringe agents is found by differentiating their minimized cost function with respect to $\overline{e}_1(t)$.

The FOC are:

$$\frac{\partial\Big[C_1[e_1(t)] + P_t[e_1(t) - \overline{e}_1(t)]\Big]}{\partial\overline{e}_1(t)} + \frac{\partial\Big[C_i[e_i(t)] + P(t)[e_i(t) - \overline{e}_i(t)]\Big]}{\partial\overline{e}_1(t)}$$

$$+\frac{\partial S_t}{\partial\overline{e}_1(t)} = 0 \tag{12}$$

For $[i = 1]$, I get the following results in the first case:

$$\frac{\partial\Big[C_1[e_1(t)] + P_t[e_1(t) - \overline{e}_1(t)]\Big]}{\partial\overline{e}_1(t)} = C_i'\left[\sum_{i=2}^{N} e_i(t)\right] \tag{13}$$

For $[i = 2, \ldots N]$, I have in both cases:

$$\frac{\partial\left[C_i[e_i(t)] + P(t)[e_i(t) - \overline{e}_i(t)]\right]}{\partial \overline{e}_1(t)} = 0 \tag{14}$$

In the first case, plugging (13) and (14) in (12), at the equilibrium the optimal permits allocation satisfies the equality:

$$-C_i'\left[\sum_{i=2}^{N} e_i(t)\right] = \frac{\partial S_t}{\partial \overline{e}_1(t)}$$

and in the second case:

$$-C_i'\left[\sum_{i=2}^{N} e_i(t)\right] + \lambda(t) = \frac{\partial S_t}{\partial \overline{e}_1(t)}$$

This equality reveals the different interests at stake when allocating permits, and may be summarized as follows:

An optimal allocation rule for a social planner with perfect foresight consists in distributing permits up to the point where an additional unit to the large agent damages consumers' surplus and establishes a dominant position affecting fringe agents' MAC.

8 Conclusion

The description of the institutional environment on which the model hinges provided a balanced picture of market power concerns in existing international emissions trading schemes. As for the Kyoto Protocol, trading rules in the making and the key role played by projections preclude from reaching a definitive conclusion, but it seems overall difficult to move an international permits market in a dynamic context. As for the EU ETS, the negotiation process of each NAP is typically an example of a manipulable rule whereby industries may conduct lobbying activities to extract more permits as a monopoly rent. With reference to the debate "rules vs. discretion" in monetary economics, there is a need for further research to ascertain the conditions under which it would be optimal to delegate the determination of the cap and the distribution of permits to an independent agency. A global conclusion concerning EU ETS market power concerns gears towards a prudent approach: if some firms have received more permits than projected, they might very well end up with a shortage of permits at the end of the first period because of an increase in emissions. Similarly, the EU Commission is especially careful during the validation of NAPs about their stringency and to the fact that there will be no ex-post adjustment.

Stemming from the description of the institutional environment of current international emissions trading schemes, I introduced a differential game with two types of agents on a tradable permits market, differing in terms of size and permits endowment, to ascertain the conditions under which a market power position may appear. Some similarities have been underlined between a benchmark case where the large agent owns all the stock and the model: in both cases where agents decide whether or not they build a permits bank, it is possible to identify net losers (i.e., fringe agents) and a net gainer (i.e., the large agent) as the large agent benefits from a lower marginal abatement cost than under perfect competition and is able to affect negatively fringe agents' marginal abatement costs. The model could be extended by the adoption of an intertemporal trading ratio specific to borrowing as discussed by Kling & Rubin (1997)[33], allowing for a better grasp of the possibilities offered by intertemporal emissions trading.

But the spectre of market power need not be raised if the cap-and-trade program appears properly designed. An optimal allocation criterion for a welfare-maximizing social planner with perfect foresight would consist in distributing permits to the large agent up to the threshold where it creates consumers' surplus losses and negative impacts on fringe agents' marginal abatement costs. From a Public Choice perspective, this "razor's edge condition"[34] highlights the difficulties encountered by the European Commission during the validation of the EU ETS Second National Allocation Plans where each national regulator needs to arbitrate between various interests at stakes. This debate between permits allocation and market power reveals the necessary compromise[35] that need to be found between various conceptions on the role of environmental regulation.

As a final comment, one could say a greater reliance on banking and limited borrowing (i.e. with a specific discounting factor) should be promoted to allow firms to smooth their emissions and take investment decisions in abatement technologies with a better capacity to react to the evolution of the carbon constraint over time.

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[33]The adoption of a discount rate penalizing borrowing may remove some of the perverse incentives whereby agents concentrate emissions on early periods, which is not socially optimal.

[34]with reference to Harrod-Domar's growth model

[35]This notion developed by Boltanski & Thevenot (1991) refers to core agreements negotiated between actors.

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